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Fourth Semi-Annual Progress Report  
for the  
Scripps Institution of Oceanography's  
University Research Initiative (URI)  
entitled  
"SCRIPPS OCEAN MODELING AND  
REMOTE SENSING (SOMARS)"

ONR Contract No. N00014-86-K-0752

Principal Investigator:  
William A. Nierenberg

Co-Principal Investigators:  
Catherine Gautier  
James J. Simpson  
Richard C. J. Somerville  
Geoffrey K. Vallis

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20 September 1988

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## INTRODUCTION

This is the Fourth Semi-Annual Report of the Scripps Institution of Oceanography's University Research Initiative (URI) entitled "*Scripps Ocean Modeling and Remote Sensing (SOMARS)*" [ONR Contract number N00014-86-K-0752]. The report covers the performance period 15 March 1988 -15 September 1988 and contains a set of unedited technical-financial statements prepared by individual scientists working on the URI. For your convenience, these statements are arranged in alphabetical order and separated by index tabs.

Should any questions arise concerning this report, please call them to the attention of:

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La Jolla, CA 92093

Copies also to URI Principal Investigators.

July 11, 1988

MEMO TO: J. Simpson

FROM: Tim Barnett 

RE: URI FY88 Budget carryover request

I had proposed to have a student look at the sensitivity of the North Pacific model to forcing by different operational windfield products. The delays and incremental nature of the URI funding last year made it impossible to hire a student with any promise of continuity in the research program. By carrying over the required funds now available (approximately \$8,000), I can plan to advertise and hire a student in the fall, hopefully completing the work some time next spring.

cc: G. Vallis and E. Cox

Update: 20 September 1988

An ad has been placed for a student to carry out the work proposed for FY89. We have three applicants at this time and expect more.

We also have obtained the necessary data to carry out the analysis from extended integrations of the ocean model.

August 12, 1988

## REPORT ON SCIENTIFIC PROGRESS

Bruce Cornuelle

Work this quarter has centered on using the Kalman filter with a linear quasi-geostrophic dynamic model to map and predict an archived combined dataset of CTD stations and current meters (not from the California current). The dataset was chosen as a preliminary test to learn about real data before the data from the URI cruises are completely worked up. The data are from a region in the Southwest North Atlantic where eddies are relatively weak, away from the Gulf Stream recirculation region. This area is expected to be similar to the offshore California current region (beyond the shelf break), and contains baroclinic eddies and/or waves in a time-varying mean flow (to the resolution of the dataset) of a few cm/sec.

The goal of the exercise is to learn about the process of validating models with real data, and to get some experience with the cross-validation potential of a real dataset. The URI is entering a stage in which the models must begin to be tested against the data, and this experiment is a dress rehearsal for one of the methods slated for use in the validation experiments with Jim Simpson, Bill Holland, and Geoff Vallis planned to start in October.

The June, 1988 progress report showed maps of 2 CTD surveys 2 months apart (day 66-85 and day 120-136) after assimilation using the Kalman filter, as well as a prediction for the second survey based on the data from the first survey and from two current meter moorings within the 300 by 300 km area of interest. The ocean is parameterized by spectral functions in 3 dimensions, with the time dependence given by quasi-geostrophic dynamics including advection by a horizontally uniform barotropic current. The present work examines quantitative measures of the performance of the Kalman filter in predicting and reproducing the data while varying the dynamics.

The measure of prediction is the ratio of the weighted prediction error variance to the original weighted data variance. The prediction error variance is the difference between the filter's prediction for the data and the actual data, and this difference is weighted (normalized) by the expected error standard deviation for each datum. Thus, a value of 0. means that the prediction had no skill, as is the case at the start of the time series. A value of 1. means that all the data was predicted by the filter, and negative values mean that the prediction went the wrong way. In Figure 1, 4 curves are plotted on the same scale, each corresponding to a hypothesized dynamics. The circles represent a filter with linear propagation and advection, the triangles represent propagation with no advection, the crosses represent persistence, and the x's represent advection with no propagation. Overall, persistence performs the best (42%) (unfortunately for the model, but in line with numerical weather prediction experience), with pure advection running a close second (40%). The prediction breaks down significantly at about day 103 for a few days, as if some anomalous, short-scale feature passed the moorings then.

Figure 2 shows a time series of weighted maximum residuals. The residuals are the portion of the observations which cannot be accounted for by parameterization, weighted by the standard deviation of the expected error. A value greater than 3 indicates that it is improbable that all the assumptions used in the analysis hold. This can mean that the dynamics are incorrect (the high values for the triangles suggest that pure propagation is not a good guess for the dynamics), or that the parameterization is too simple, or the assumed errors too small. This figure would suggest that the simple linear propagation model is contradicted, while persistence and uniform barotropic advection are acceptable hypotheses.

Taken together, these results suggest that non-linear dynamics are important for assimilation even in regions of weak eddy activity. Given the error levels assumed for the dataset in this run, the ability to distinguish between good and bad dynamics is limited. Data error must include both instrument error and ocean "noise", such as internal wave displacements of the mesoscale field. The internal wave displacements may dominate the error budget for hydro casts (and for moored

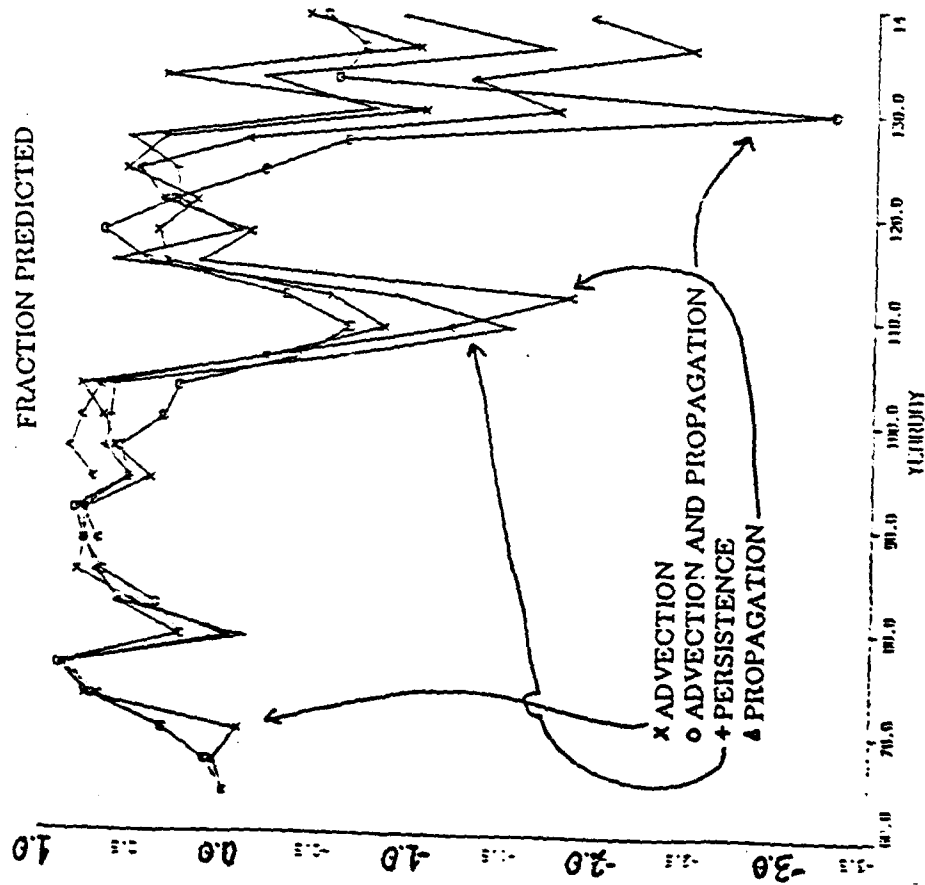


Figure 1: Fraction of variance predicted vs year/day  
for current meter data and CTD casts.

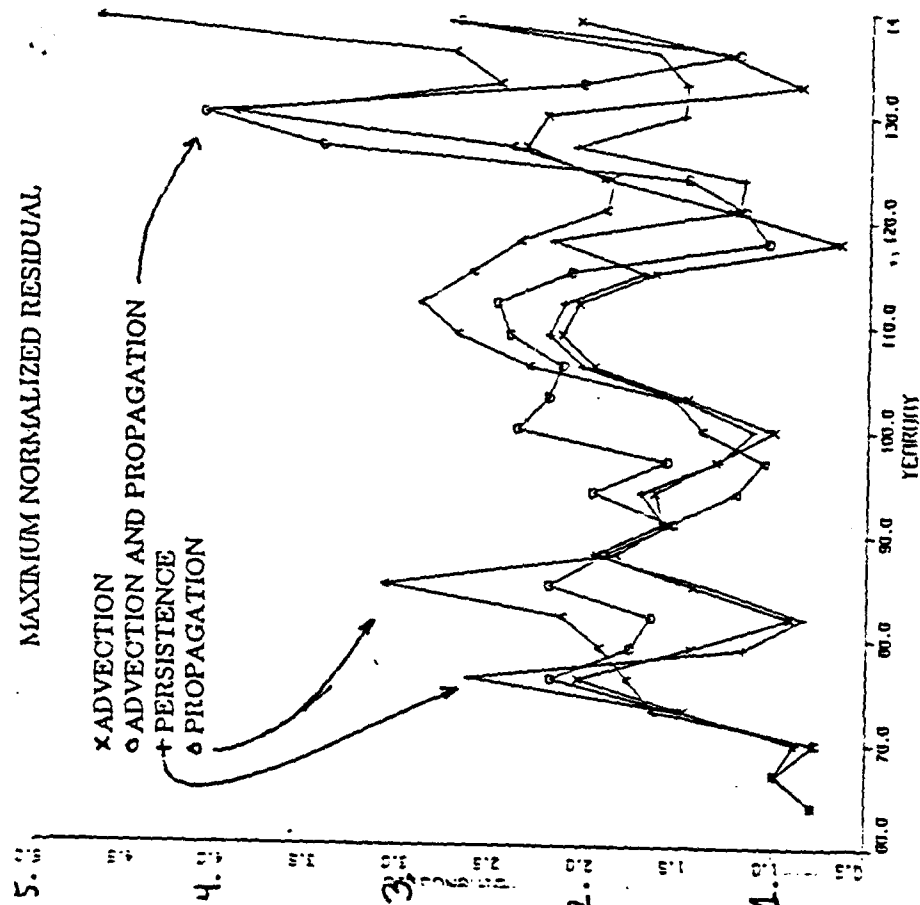


Figure 2: Maximum residual from fit,  
normalized by error standard deviation.

temperature sensors, in spite of the time averaging possible in the latter case). Quantitative calculations are under way for the test dataset. In a region with a small ratio of eddy displacements to internal wave displacements, validation of a model using hydro casts may be very difficult if the stations alias significant internal wave energy into the eddy field.

Jim Simpson is examining the vertical modal structure of the URI cruise data, and one of the next steps in this work is to estimate the signal-to-noise levels for validation of California Current models. Internal wave displacements are unimportant compared to orbital and humidity errors for the error budget of altimeter data. And a similar experiment should be carried out for altimetric data, also in preparation for the availability of a cleaned Geosat dataset for the California current region.

## REPORT ON FINANCIAL ACTIVITY

Bruce Cornuelle

I have used 3 months of salary from the URI budget, but have not yet used the page charges or travel monies. I have not hired a summer student because I will be at a conference in August, and at sea in September, returning October 10th.

# Remote Sensing

## SST, Altimetry, and Surface Heat Fluxes

Catherine Gautier and Philippe Collard

Our work during the last several months has focused on three areas involving remote sensing observations: (1) comparison between AVHRR-derived sea surface temperature (SST) patterns and Geosat-derived topography variability, (2) pattern detection and analysis in SST images, and (3) SST analysis for heat transport and flux computations.

### (1) AVHRR SST vs Geosat topography

The main scientific objective of this activity is to explore ways in which we can use the high spatial information contained in satellite-derived sea surface temperature imagery to increase the spatial resolution of topography estimations made from Geosat altimetry measurements. The presence of eddies in the California Current, for instance, should be detectable in both SST and altimetry observations.

Our approach to achieve this objective is to first compare concomitant observations of the California Current region made with both AVHRR and Geosat. The main problems faced in this comparison are linked to the difference between the two data sets and the peculiarities of each data set:

(a) SST fields derived from satellite infrared measurements represent the surface signature (a few microns) of the thermal field and the relationship between surface signature and temperature below is not always known.

(b) infrared measurements from space are opaque to clouds, thus we can only have a surface signature of the thermal field in cloud-free cases. This seriously limits the number of possible comparisons.

(c) Geosat-derived information represents the variability ( $\eta'$ ) of the topography from a time mean ( $\bar{\eta}$ ) along each repetitive track ( $\eta' = \eta_{\text{inst}} - h_{\text{geoid}} - \bar{\eta}$ ).

Our inventory of clear days for SST analysis from the start of the Geosat exact repeat mission (ERM) indicates very few possible days for comparison. For our first analysis, we have chosen three relatively clear time periods around the beginning of 1987. Two sets of comparisons have been performed: (1) a comparison between  $\eta'$  and SST along one track on the same day, (2) and a comparison between  $\eta'$  mapped over a 17-day period and the SST field averaged over that period. Both of these comparisons were performed for a region off Baja California. The results of these comparisons were presented at the last site review. They showed good qualitative agreement between the two sets of observations but indicated a problem in interpretation related to the discrepancy between the comparisons of an



instantaneous field (SST) and an "anomaly" field (topography). Thus, we now propose to establish a time-averaged SST map in order to compute an SST "anomaly" field corresponding to the topography "anomaly". Furthermore, we will extend this type of analysis for as many days as we can find that are clear off the coast of California.

## (2) Pattern detection and analysis in SST images

The main objective of this activity is to automatically detect and analyze SST features in order to perform some statistical analysis on them and build a "climatology" of these patterns.

We have completed development of the tools needed to start the purely research aspect of this work. We now have a large set of mathematical tools that can be applied to AVHRR SST images for the detection of significant patterns.

We have started working on the detection of these patterns first by applying rather well known pattern recognition techniques, but there were a few obstacles to overcome prior to being able to do so. A well known and accepted edge/pattern detection method consists in the computation of the intensity gradient in an image followed by the computation of the frequency histogram of the resulting gradient image. From the frequency histogram, we compute a cut-off value then we use this cut-off value to "clean up" the image. The result is an image containing the edges only. The edges are defined as being the pixels with the highest gradient values. From the frequency histogram, we compute the cut-off value that gives a set of edges formed by 10% of all the pixels in the image. A problem can occur when computing the gradient in SST images if land or clouds are present in the image. We have been able to devise a method to remove land from the original SST images but we must still be careful when computing the gradient because of the artefacts created by the difference in temperature between land and ocean on the coastline. We have not yet attempted the removal of clouds from images, but our group has developed a method that could accomplish this objective. Still, the removal of the clouds will also have an impact on the computation of the gradient and will have to be accounted for.

The results of the method we have just described were not as good as expected. This is because edges can be found in these images at different scales (small to medium to large). We are interested mainly in the medium scale features (10 to 100 km), but the gradient method does not take this into account. In order to be able to select features at a certain scale, we have applied several filters to the images. First a low pass filter (called the DRF filter for Difference Recursive Filter) and a step filter (a filter whose frequency response has the shape of steps). Both these filters improved our edge detection technique but did not give us results completely satisfactory.

We plan to explore two directions in order to overcome this problem: first we will use mathematical morphology techniques (like erosion) to see if we can

remove smaller scale features from our set of edges. We also plan to perform 2D Fourier analysis to determine what are the different scales in our images.

When our edge detection technique is finely tuned, we will combine these edges to detect significant patterns and characterize them. The results will be stored in a database to help subsequent analyses.

### (3) SST analysis for heat transport and flux computations

The main objective of this activity is to assess how well we can estimate upper ocean heat transport using a heat budget analysis obtained entirely from remotely sensed observations.

The rationale behind this analysis comes from some of our observations of SST evolution over a 15-day period in the winter time (January-February 1987) which indicated that the observed SST change (negative) was taking place over a relatively large scale (500 km), indicating that the cooling was resulting mostly from atmospheric processes (i.e., surface heat fluxes). This was supported by noticing that the dynamical features in the SST field have very small scales (see discussion on edges above) and also demonstrated by performing averages of the SST difference (from two images separated by about 15 days) over varying spatial scales. This average provided very similar results from 500 km down to scales of a few 10s of kilometers.

If one looks at the heat budget equation, this means that  $\vec{V}_s \cdot \nabla \bar{T} = 0$ , or the ocean heat advection is negligible over the time period involved and over the scales for which the difference is equal/close to that of the large scale. The averaged value corresponds to the surface heat flux  $F_s$ . From the equation we can also compute ocean surface current ( $\vec{V}_s$ ) since we can calculate  $\nabla \bar{T}$  from the SST images.

We are presently performing these computations and checking the consistency of our  $\vec{V}_s$  estimates with the climatological ones in the California Current region for the winter. Additional consistency checks will be performed using observed winds.

We propose to systematically redo these types of computations for two additional time periods and also compute the net cooling ( $Q_c$ ). The cooling will be obtained from  $Q_c = F_s - SW$ , where SW is the solar irradiance at the surface (the only heating term in the surface heat flux) to be obtained from satellite data following our method. Furthermore, we will compute the latent heat flux part of  $Q_c$  using the SSM/I data and the method developed by T. Liu.

9/21/88

RESIDUAL BALANCE SHEET  
URI N00014-86K-0752

P.I. GAUTIER  
586490-25912  
BUDGET #3846

	BALANCE AS OF AUG 31, 1988	PROJECTED EXPENSE	PROJECTED BALANCE SEPT 30, 1988
SALARIES & BENEFITS	5 472.	2,405.	-1,933.
SUPPLIES & EXPENSE	6,440.	4,000.	2,440.
EQUIPMENT	4,961.	4,961.	-0-
TRAVEL	1,000.	1,000.	-0-
DIRECT TOTAL	\$12,873.	\$12,366.	\$507.
OVERHEAD-45%	5,793.	5,565.	228.
BUDGET TOTAL	\$18,666.	\$17,931.	\$735.

PREPARED BY  
VIRGINIA FLOYD

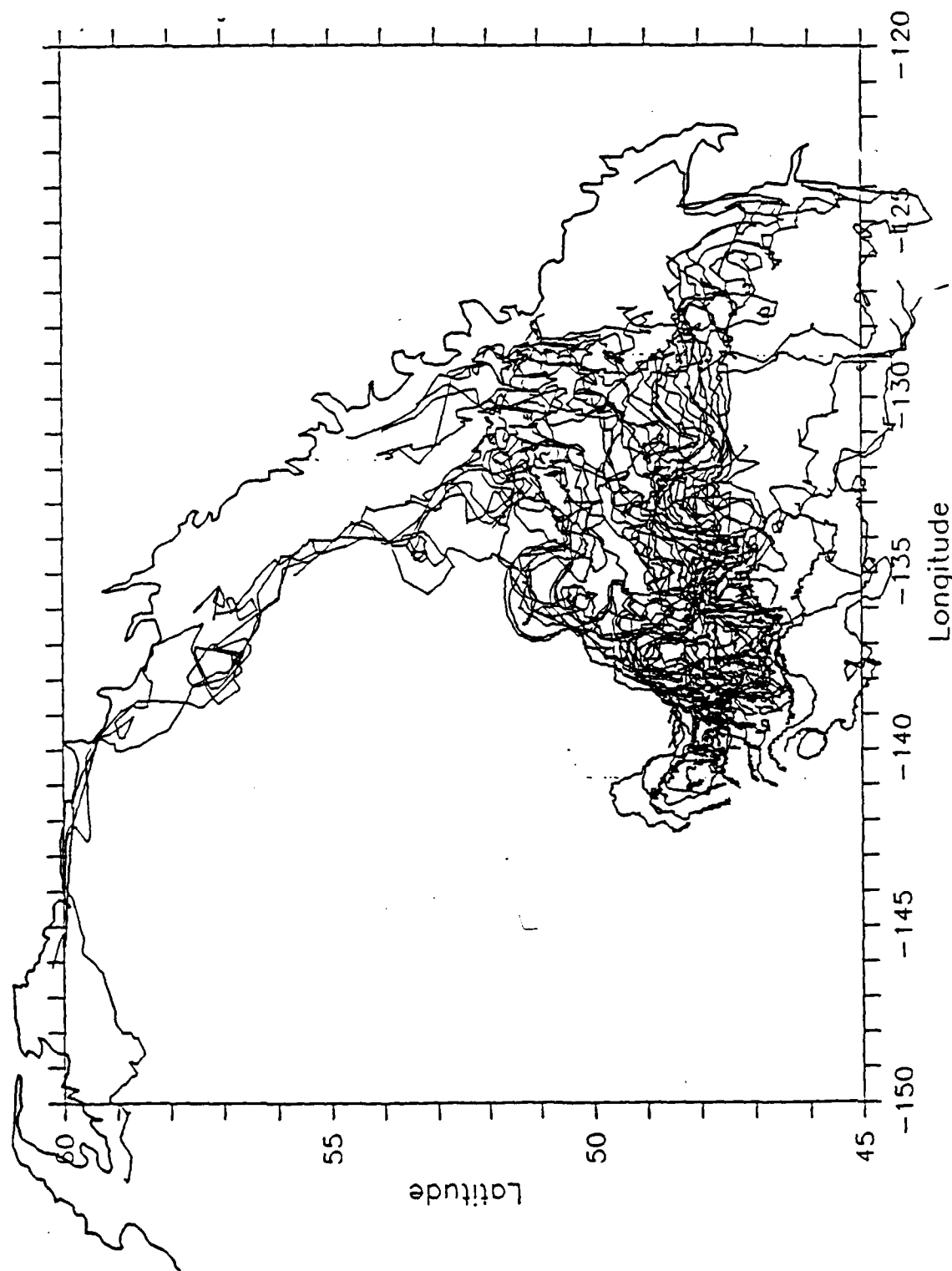
9/21/88

RESIDUAL BALANCE SHEET  
URI N00014-86K-0752

P.I. GAUTIER  
586493-25912  
BUDGET #3850

	BALANCE AS OF AUG 31, 1988	PROJECTED EXPENSE	PROJECTED BALANCE SEPT 30, 1988
SALARIES & BENEFITS	-3,071.	2,000.	-5,071.
SUPPLIES & EXPENSE	6,358.	1,460.	4,898.
EQUIPMENT	1,640.	1,640.	-0-
TRAVEL	214.	-0-	214.
DIRECT TOTAL	\$5,141.	\$5,100.	\$41.
OVERHEAD-45%	2,313.	2,295.	18.
BUDGET TOTAL	\$7,454.	\$7,395.	\$59.

PREPARED BY  
VIRGINIA FLOYD



Tracks of TRISTAR mixed layer drifters from October, 1987 to June, 1988 which were released in OCEAN STORMS Experiment. This data base is now being analyzed for single particle diffusions and wind response for the purpose of comparison with the eastern Pacific model of ocean circulation.

Pearn Niiler A-030

Marine Life Research

Fund Management for 3853

09/15/98

593541-25912

URI/ONR Univ.Res.Initiative/N00014-86-K-0752

Expires 09-14-91

SUB	Allocation	Prior Expense	Current Expense 8909	Outstanding Expense	Total Expense	Lien	Balance
2 Staff Salary	34600.00	29291.74	8804.33	0.00	38096.12	0.00	< -3486.12 >
3 Supplies & Expense	4000.00	152.19	0.00	0.00	152.19	0.00	3847.81
4 Equipment	2000.00	1871.95	0.00	0.00	1871.95	0.00	128.05
7 Other Expenses	0.00	814.50	0.00	0.00	814.50	0.00	< -814.50 >
Direct Total	40600.00	32120.38	8804.33	0.00	40924.76	0.00	< -324.76 >
Overhead - 0.4500	16969.00	13267.13	3961.97	0.00	17229.10	0.00	< -260.10 >
Budget Total	57569.00	45387.51	12766.35	0.00	58153.86	0.00	< -584.86 >

< ... > INDICATES A DEFICIT BALANCE.

From Sadie x4-3567

Semi-Annual Report for Scripps URI

15 March 1988 - 15 September 1988

James J. Simpson

I. SCIENTIFIC ACTIVITY

The in situ/remote sensing activity over the past six months has concentrated on three activity areas:

- A. Integrated System Development
- B. Experiments at Sea
- C. Coupled in situ data and image analysis.

A. Integrated System Development

Work has continued on the development of the integrated seagoing in situ/remote sensing system. This system is designed to provide a four-dimensional representation of the ocean-atmosphere environment in quasi-real time. Milestones in the past six months work include:

1. Image Analysis

(a) GTILE

The GTILE platform has been expanded to include:

- i. multiple image support
- ii. classification of images
- iii. large image data set input/output capability
- iv. better error trapping.

GTILE has proved to be a robust, general purpose image analysis platform which has greatly facilitated our generation of image analysis applications software.

(b) Advective Velocity Procedures

Computation of advective surface velocities using NOAA AVHRR satellite imagery is being tested using three comparative methods.

The first method utilizes a subjective feature tracking algorithm. The first image in a time series is displayed, and the user determines features which appear in the first image which can be tracked in the second image. Velocity vectors are calculated using the feature displacement and time difference between the two images. Advantages of this method are that it is fast and easy to use. Disadvantages are that two clear images are necessary and that the method is totally subjective.

A second method uses statistical inference to objectively track features. This second method takes the images of a time series as input and calculates the cross-correlations of subsections of spatially overlapping areas. In the most perfect case, the location of the maximum of the cross-correlation of two images represents the displacement of the second image relative to the first. Two implementations are used. One implementation uses the method of Fast Fourier Transforms to increase the speed of computation. The second implementation uses a variation on the direct definition of cross-correlations for its computation. The advantage is that the method is totally objective. Disadvantages are the relatively long time of computation and that two clear images are necessary. Results obtained using these two implementations of the statistical inference method are shown in Figures 1-6.

A third method, still in the development stage, is based on inverse computational methods. Using basic equations of fluid dynamics concerning conservation of mass and energy, this method takes the temperature field represented by an image and computes the best estimate of the velocity field. The distinct advantage of this method is that it requires only one clear image. Since it is very difficult to obtain a clear time series of satellite images, this advantage could prove to be very important. The disadvantage of this method is that depending on the available information, the velocity field approximated may not be a good representation of the actual velocity field.

We expect to have a detailed intercomparison of the three different procedures as well as sensitivity tests for each of the computations done within the next several months. This work is being done with my graduate student, Mr. Darrin Wahl.

(c) GEOSAT Data Structure

Considerable effort has been expended recently in converting altimetry data over the oceans recorded by the Geosat satellite into a format usable in an image-processing environment. Data amounting to 130 megabytes (in ASCII format, encapsulating the period from October 1986 to December 1987) were received in July from NASA. Early tasks involved breaking up the data into 488 separate components, each representing a Geosat track (half of a polar orbit around the Earth along which data is taken at intervals of approximately every 17 days), plotting data points in a given region to ensure that the data was in the track format prescribed by NASA (this also allowed the determination of track-finding algorithms), and developing a subsampling technique which would selectively reduce the size of the database by recording the points of tracks selected which fell within latitude and longitude boundaries selected by the user.



An immediate result of this was strip plots on subsampled tracks over several repeats of data taken at 17 day intervals that allowed feature tracking. Subsampling also decreased the amount of information for the computationally expensive optimum interpolation process, which was extensively modified to allow construction of an image. Since the original structure of the data set is organized on a criss-crossing track basis, extrapolating evenly spaced data points at a specific time via the optimum interpolation process was a necessity for compatibility with existing image processing techniques. A complicated selection algorithm was devised to efficiently search through the data tracks for points near a row-column point to be interpolated (and on which the interpolated point is based by covariance methods). In short, the interpolation program was generalized to work on any set of parameters and subsamples for the production of images from subsampled Geosat altimetry data which may then be analyzed by image-processing techniques.

A one-year AVHRR data base, contemporaneous with the GEOSAT data, also was constructed. Presently, we are combining GEOSAT and AVHRR data to determine mesoscale eddy variability in the California Current using a variety of mathematical techniques (e.g., optimal interpolation, empirical orthogonal function analysis).

## 2. In Situ Data Processing

Over the past six months we have concentrated on 1) an automated approach to the correction of time response differences between temperature and conductivity data (this is a generic feature of CTD instrumentation), and 2) the evaluation at sea of a new pumping retrofit to the SeaBird CTD. The results are very good. A manuscript describing the new computation procedure and its effect on salinity spike removal is in preparation.

### B. Experiments at Sea

A 30-day cruise, 27 August- 22 September 1988 to measure mesoscale structure in the California Current is near completion. Shiptime was provided by the University of California. Dr. E. Venrick was the Chief Scientist. Drs. P. Niiler, T. Chereskin, and J. Simpson plan to combine different methods for estimating near-surface velocity. Niiler will deploy Lagrangian drifters, Chereskin will operate a Doppler Acoustic Log, and Simpson will compute velocity from remotely-sensed data.

### C. In Situ - Remote Sensing Analysis

Over the past six months, several advances have been made in our data analysis efforts. Highlights include:

- 1) Two manuscripts are near completion --

Simpson, J. J., and R. J. Lynn: A vortex dipole in the offshore California Current. To be submitted to J. Geophys. Res.

Lynn, R. J., and J. J. Simpson: On the continuity and stability of the California Undercurrent. To be submitted to J. Geophys. Res.

- 2) Developed our second method (automated cross-correlation procedure) for computing near-surface velocity from AVHRR (Figures 1-6).

## II. COOPERATION WITH NAVY LABS

### A. Naval Environmental Prediction and Research Facility (NEPRF)

#### 1. Image Analysis:

Currently, I am working with Bob Fett and Ted Tsui on the test and evaluation of commercially available image processing systems. In addition, we anticipate porting some of the code that is generated on my H-P system to NEPRF for their use.

#### 2. Seagoing Analysis:

Dennis Perryman (NEPRF) participated on the February-March 1987 URI cruise. He made radiosonde measurements concurrently with our CTD and meteorological flux measurements. Dennis and I are now working on a manuscript which discusses the atmospheric structure above an offshore mesoscale eddy in the California Current.

### B. Naval Ocean Systems Center (NOSC)

Cooperative work has continued on the analysis of data taken during the first URI cruise (VAL, 14 February-21 March 1987). Primary contact has been with Dr. Paul Fiedler, an Office of Naval Technology post-doctoral trainee at NOSC. Over the next several months, we anticipate interactions on the VAL analysis to also involve Dr. Ken Richter (Doppler Acoustic Log data) and Dr. Al Zirino (chemical profiles in the upper ocean).

### C. NAVOCEANO and NORDA

During August 1988, I visited both NAVOCEANO and NORDA and gave a seminar on image analysis. Both commands expressed serious interest in long-term interactions in the area of remote-sensing. NAVOCEANO will issue travel orders for the first week in November to begin this interaction. We will work with the transition group to help them get UNIX/C based image analysis software running on their operational computers. We also expect to work with Jeff Hawkins, NORDA, on cloud removal algorithms.

### III. EDUCATIONAL ACTIVITIES

Dr. Barbara Eckstein, a URI postdoctoral research assistant, continues to work on the development of long time series of Coastal Zone Color Scanner (CZCS) data. She will use these to compute eddy statistics.

Mr. Darrin Wahl, a URI graduate student, has worked extensively on the development of our automated cross-correlation procedure to determine near-surface velocity from AVHRR and CZCS data. This is our second method for determining velocity from image data.

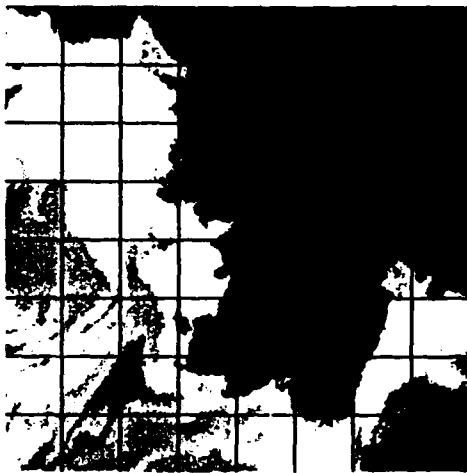
Mr. Chris Humphrey and Mr. John Toman, undergraduate engineering and computer science students at UCSD, are working on a variety of image analysis applications programs.

### IV. ADMINISTRATION

During the past year and a half, I have served as Secretary of the Executive Committee. As such, I have been the principal liaison between the Executive Committee and UCSD Contracts and Grants, CalSpace Contracts administrative personnel, the ONR Resident Representative Mr. R. Bachman, and ONR Washington. Preparation of reports, budget reviews, individual investigator requests for budgetary reprogramming authority, and the like constituted the major part of this administrative function.

### V. FINANCIAL STATEMENT

We anticipate having a few thousand dollars carried over to FY89 once the September payroll expenses are met. Items which have been liened against previously issued University P.O.s include a few pieces of equipment which have not yet arrived. These invoices will be paid on the liened 1988 budget once the equipment is received and judged operational.



**Figure 1**



**Figure 3**



**Figure 2**



**Figure 4**

**Figure 1: NOAA-9 AVHRR IMAGE 28JUN88 23:36:00 HOURS NEAR LAT:37N LON:126W**

**Figure 2: NOAA-10 AVHRR IMAGE 29JUN88 02:57:30 HOURS NEAR LAT:37N LON:126W**

**Figure 3: ADVECTIVE VELOCITY FIELD USING SPATIAL DOMAIN METHOD**

**Figure 4: ADVECTIVE VELOCITY FIELD USING FREQUENCY DOMAIN METHOD**

**Figure 5: ENLARGED VIEW OF FIGURE 3 VELOCITY FIELD**

**Figure 6: ENLARGED VIEW OF FIGURE 4 VELOCITY FIELD**



Figure 5



Figure 6

## MIXED LAYER MODELING IN THE SCRIPPS URI

Fourth Semi-Annual Progress Report  
15 March 1988 to 15 September 1988

Richard C. J. Somerville

During the reporting period, we have carried out extensive testing of the one-dimensional version of our coupled air-sea model. This model is a simple Niler-Kraus-Turner type of ocean mixed layer model (MLM), based on the integrated turbulent kinetic energy equation, coupled to an atmospheric radiative-convective model (RCM). At the air-sea interface, a full surface energy budget is computed. Solar and infrared radiative transfer is included, together with parameterizations of latent and sensible heating and momentum fluxes.

The current version of the MLM includes entrainment at the lower interface, but mean velocity fields are not taken into account. The RCM, however, includes internally computed vertical transfers of heat, momentum and moisture, together with internally generated clouds and externally specified mean horizontal flux divergences. In a series of test integrations over several simulated weeks, the time-dependent coupled model has produced fairly realistic distributions of temperature when driven with observed winds taken from FGGE analyses. Much useful information has been obtained on the sensitivity of results to uncertainty in the input data, on the time resolution and numerical procedures required for straightforward synchronous coupling, and on the effects of varying the atmospheric vertical transfer parameterizations.

This version of the coupled model closely resembles a single column of a typical atmospheric general circulation model (GCM) coupled to an oceanic MLM. The treatments of radiative transfer, clouds, vertical transports and surface fluxes in the RCM are all closely based on current GCM practice. The MLM, however, is an idealized model incorporating concepts which were developed a decade ago. It is economical computationally, with a test integration typically requiring a few minutes of Vax time. Thus, it has been possible to run many test cases in the course of carrying out the initial sensitivity studies. This model has been useful as a first step in developing a hierarchy of coupled models, but the state of the art has advanced beyond such simple vertically integrated models. It is time to replace the MLM with a modern model which takes account of vertical variability and is more physically comprehensive.

Future work should proceed in several parallel directions. One is the upgrading of the MLM itself, of course, but it is time to move beyond mixed layer modeling carried out by one or two scientists working part-time and essentially in isolation from the remainder of the Scripps URI. A second direction, which should not be delayed any longer, is the task of merging this research with the ocean modeling component of the URI by incorporating a MLM into a three-dimensional ocean circulation model and forcing this model with both simulated and actual atmospheric data. This step is at the heart of the URI program. It is important to proceed with three-dimensional modeling while at the same time continuing to work on improving the MLM off-line.

A third direction, which offers considerable promise for taking advantage of the MLM as a four-dimensional data assimilation tool, is the inverse approach recently described by Gaspar and André of the National Center for Meteorological Research in Toulouse, France. In the inverse mode, the MLM provides surface fluxes as output when it is forced with observed ocean properties. By recursively alternating the direct and the inverse modes, the model can be used to find the upper ocean state which best fits both observational and dynamical constraints. This idea can be tested and developed in simple models before being incorporated in a fully coupled three-dimensional model.

The pace of this work will depend on the resources devoted to it. ECOM initially envisaged hiring a postdoctoral fellow to be dedicated to mixed layer modeling. Budget limitations have not permitted us to fill this position to date. Additionally, whether or not a Ph.D. student will be willing to carry out dissertation research in this area will also depend in part on the likelihood of adequate and stable future funding. It is time to reconsider mixed layer modeling in the Scripps URI, from the standpoints of both scientific priorities and resource allocations.

9/2/88

RESIDUAL BALANCE SHEET  
URI NOOC:4-86K-0752

P.I. - SOMERVILLE  
582470-25912  
BUDGET # 3851

	BALANCE AS OF AUG31,1988	PROJECTED EXPENSES	PROJECTED BALANCE SEPT30,1988
SALARIES & BENEFITS	\$3,342	\$3,068	\$274
SUPPLIES & EXPENSES	(\$757)	\$0	(\$757)
EQUIPMENT	\$64	\$0	\$64
TRAVEL	\$500	\$0	\$500
 DIRECT TOTAL	 \$3,149	 \$3,068	 \$81
OVERHEAD-45%	\$1,417	\$1,381	\$36
BUDGET TOTAL	\$4,566	\$4,449	\$117

PREPARED BY:  
JOAN DURKIN



16 September 1987

TO: J. Simpson/ECOM  
FROM: Robert Stewart  
SUBJECT: URI Progress Report

During the last six months I have worked on several tasks that contributed to the University Research Initiative entitled "Scripps Ocean Modelling and Remote Sensing". The work was done mostly at no cost to the contract, although a small amount of computer time and other resources were required.

### MIXED-LAYER STUDIES

Working with Peter Niiler, I obtained funding from ONR for a post-graduate assistant who will calculate the interannual variability of the mixed layer in the Northeastern Pacific using conventional observations. The goal of the work is to determine the accuracy with which the depth of the mixed layer can be calculated and to determine the accuracy of the measurements required for calculating the depth accurately. The latter will help the Navy determine requirements for future satellite systems for observing the sea surface.

The work is being funded by a separate ONR contract, but the results will contribute directly to this URI, and the work is being coordinated with work by Geoff Vallis.

### PLANNING OF RADAR EXPERIMENT FOR ALTIMETRY

The dominant uncorrected error in altimetry, exclusive of that contributed by the uncertainties in the satellite's ephemeris, is that due to the influence of ocean surface waves. The error is about 1-5% of significant wave height, but the value is uncertain by perhaps 100% of its estimated value. I have been planning experimental and theoretical studies of the variability of radar scatter at vertical incidence as a function of wind and wave conditions. The work is cooperative with Profs. Ken Melville and Jin Kong of MIT. The first experiment begins this month at the Navy's SAXON experiment on the Chesapeake Bay Light Tower. The results of the experiment will provide a better means for correcting wave-induced errors in altimetry; and they will be directly useful to the URI investigations of the California Current. I have also begun analyzing previously recorded wave data to determine the skewness of the ocean wave field, another variable needed for understanding sea-state bias.

The experiment is being funded primarily by NASA with some contributions from the Navy through the Accelerated Research Initiative on Ocean Surface Wave Dynamics. I have not charged any URI time to this task, but I have used the Alliant computer for some small analyses of wave data and for planning the experiment.

*TEACHING METHODS OF SATELLITE OCEANOGRAPHY*

An important goal of the research initiative is the teaching of a new generation of oceanographers skilled in the use of satellite and remote sensing techniques. In the winter quarter of 1987-1988 I taught a course on the Methods of Satellite Oceanography to five graduate students who are interested in using satellite measurements in their thesis work.

## SIO URI PROGRESS REPORT (SEPTEMBER, 1988)

Warren B. White and Chang-Kou Tai

### 1.0 Model/Data Intercomparison Between the Mesoscale Eddy Activity Determined from GEOSAT Altimetric Sea Level and From the Wind-Driven Non-Eddy Resolving Numerical Model of the California Current

Estimates of the time and space scales of the mesoscale eddy activity in the California Current region from 20°-50°N, 140°W to the coast of North America were made possible for the first time by the advent of the GEOSAT altimetric satellite. Analysis of altimetric sea level obtained during the first year of the GEOSAT Exact Repeat Mission (ERM) from November 1986 to October 1987 was conducted and reported in White and Tai (1989). The RMS of altimetric sea level about the one-year mean, associated principally with mesoscale eddy activity, was maximum along the coast of North America, with spatial maxima in RMS differences occurring at three latitudes; i.e., south of the Cape Mendicino from 37°-40°, southwest of Point Conception near 33°N, and adjacent to Point Eugenia near 27°N, not seen earlier. Empirical orthogonal function analysis of these data indicated the mesoscale eddy activity to have been dominated by the annual cycle. Wavenumber/frequency spectra of the altimetric sea level residuals were computed both in the zonal and meridional direction for the one-year period, indicating westward and northward phase propagation with a dominant zonal wavelength of approximately 1000 km and a dominant period of 4 to 6 months, propagating at baroclinic Rossby wave speeds. On these dominant time and space scales, little evidence exists that mesoscale eddy activity was advected by the southeastward flow of the California Current. The geographical distribution and time/space character of the observed mesoscale eddy activity indicate that wind stress, bathymetry, and coastline topography all played roles in the eddy generation off Point Conception, Point Eugenia, and Cape Mendicino; i.e., instability apparently has a role in the generation of mesoscale eddy activity on smaller period/wavelength scales than those (i.e., 4 to 6 months, 500 to 1000 km, respectively) dominating the GEOSAT altimetric sea level estimates in the California Current.

On the basis of these results reported by White and Tai (1989), White, Tai, and Holland (1989) hypothesized that these larger scales of mesoscale eddy activity (particularly on period/wavelength scales greater than two months and 400 km) could be simulated by a realistic wind-driven non-eddy resolving model of the California Current region, examined already by Bates *et al.* (1989). In the Bates *et al.* (1989) study, a comparison between the non-eddy resolving model and the long-term mean statistics were conducted, establishing that the model could simulate the qualitative aspects of the mean circulation found in the

CalCOFI observations of the California Current region (i.e., the California Current and the California Counter/Under Current), as well as the annual cycle, but not its quantitative aspects; i.e., the  $1^\circ$  resolution of the model, exacerbated by the  $2^\circ$  resolution of the wind stress forcing of the model, precluded resolving the proper width and intensity of these currents (i.e., their vertical structure was, on the other hand, simulated quantitatively). In the model analysis conducted by White, Tai, and Holland (1989), the mesoscale eddy activity for the one-year period (November, 1986 to November, 1987) of the GEOSAT ERM was compared with the results of the non-eddy resolving model; these model results simulated quantitatively the annual cycle of the sea level observed in the GEOSAT altimetric data, particularly north of Point Conception; south of that location the lack of eddy resolving capability in the model seems to preclude agreement between the model and the altimetric sea level observations.

## 2.0 Continuous Assimilation of Simulated Referenced GEOSAT Altimetric Sea Level Differences into Wind-Driven Eddy Resolving Numerical Ocean Models

The continuous assimilation of referenced altimetric sea level differences from the simulated GEOSAT Exact Repeat Mission (ERM) into a three-layer, quasi-geostrophic, eddy resolving numerical ocean box model at mid-latitude was conducted using an improved version of the optimal interpolation method utilized in White, Tai, and Holland (1989), forming the basis of an operational regional dynamical interpolation procedure to be used in the assimilation of real GEOSAT ERM altimetric sea level data into an eddy resolving numerical ocean model of the California Current. The major improvement over the optimal interpolation method used in White *et al.* (1989) is the inclusion of temporal decorrelation in the error covariance matrix. Assimilation was conducted in a nowcast mode as the referenced altimetric sea level differences were measured in real time by the simulated GEOSAT altimeter, with attention focused upon the ability of the dynamical interpolation procedure to construct a mesoscale eddy field resembling that of the control model integration. The results of this dynamical interpolation procedure were compared with the ability of a statistical (i.e., optimal) interpolation procedure to reconstruct the mesoscale eddy field of the control model integration ( $30^\circ$ - $40^\circ$ N,  $140^\circ$ - $165^\circ$ E), used presently in the construction of mesoscale eddy maps in the California Current region (White and Tai, 1989). A series of model experiments was conducted, with initial conditions independent from that of the control model integration (the latter taken to represent the observed sea level fluctuations associated with the mesoscale eddy field), where the dynamical interpolation was able to reproduce the control model integration (explaining 95% of the control model variance) after only two repeat cycles (i.e., 34 days) of the GEOSAT Exact Repeat Mission (ERM). The degree of similarity between the upper-layer streamfunction of the updated model and the control model integration after two repeat cycles was statistically greater than that achieved by statistical interpolation (explaining only 75% of the control model variance), both interpolation procedures (i.e. dynamical and statistical) using covariance estimates that were determined *a priori*. The additional advantage of the dynamical interpolation is that after two cycles of the GEOSAT ERM, mesoscale eddy activity in the middle and lower layers of the updated model integration also began to resemble that of the model control integration (explaining 35% and 50% of the control model variance, respectively), without

resorting to vertical statistical interpolation, unless a vertical statistical interpolation is employed, in which case the resemblance of the resulting mesoscale eddy activity to that found in the model control integration is much less than with the dynamical interpolation (explaining only 25% of the control model variance).

Therefore, the next step in the continuous model/data assimilation (i.e., dynamic interpolation) effort is the assimilation of real GEOSAT altimetric sea level into a realistic wind-driven numerical model of the California Current region. In the previous section (i.e., 1.0), a comparison was made between the mesoscale eddy activity in a non-eddy resolving model of the California Current and that observed in GEOSAT altimetric sea level (mapped by statistical interpolation), indicating that a portion of the dominant mesoscale eddy activity (i.e., with period ranging from 4 to 6 months and wavelengths ranging from 500 to 1000 km) was being simulated by the model; this suggests that mesoscale eddy activity in the model is governed by some of the same dynamics governing mesoscale eddy activity in the real ocean. Therefore, we propose to begin constructing sea level maps of the mesoscale eddy activity in the California Current using dynamical interpolation; i.e., by assimilating the GEOSAT ERM altimetric sea level into the realistic non-eddy resolving model of the GEOSAT ERM altimetric sea level data into the realistic eddy resolving model of the California Current, which is due to be operational at SIO in January of 1989. The criterion for determining the improvement of this dynamical interpolation of the GEOSAT altimetric sea level, over that conducted statistically (White and Tai, 1989), will be whether it stimulates better the baroclinic structure of eddy activity observed by hydrographic measurements.

### 3.0 Interaction with Naval Laboratories and the Naval Operational Community

Since the last progress report, much has happened concerning the interaction with Navy laboratories and the Naval operational community.

In the past three months, FNOC in cooperation with NOS and SIO (specifically Warren White), has agreed to release to the civilian community classified XBT data that have declassification dates on them (i.e., approximately half of all classified XBT data). From an NSF grant obtained by Warren White, Roger Bauer of Compass Systems has been contracted to work at FNOC, developing software that will allow these "declassified" XBT data to be automatically included in an unclassified data file upon expiration of the declassification date. This means that in the California Current region much better XBT coverage will now be available with which to compare with both the GEOSAT altimetric sea level and numerical model data. A student (see below) has agreed to conduct a comparison between the dynamic height (0/400 db) computed from these XBT data (i.e., utilizing historical T/S relations) and the sea level activity measured by the GEOSAT ERM.

In the past two months, Drs. Harley Hurburt and Donn Blake from NORDA, have expressed a desire to coordinate their modeling activities in the eastern mid-latitude North Pacific (i.e., including the California Current region), with the activities presently ongoing in the SIO URI. They are expressly interested in collaborating both on the development and implementation of model/data

assimilation techniques, and on model verification. They plan to visit SIO in October to discuss the implementation of this collaboration. C.-K. Tai and Warren B. White see this collaboration as an important contribution by NORDA to the objectives of the SIO URI. Moreover, it is an opportunity for the orderly transfer of software technology from SIO to the Navy operational community. To facilitate this, it may be necessary for one or more of the NORDA personnel to conduct an extended visit at SIO during the later half of the URI, strengthening the collaboration between SIO and the operational Navy community. An additional possibility is that SIO operate the California Current eddy resolving model in a near-real time (i.e., nowcast/forecast) mode for both Navy and its own civilian use, following a precedent established with the SIO Remote Sensing Facility.

In the past two months, Dr. Warren White also attended a summer colloquium conducted under the auspices of the Institute of Naval Oceanography (INO), chaired by Dr. Christopher Mooers. At these meetings (held at Otter Creek during July 27-29, 1988), the task team approach taken by the SIO URI was promoted as a paradigm for developing a capability of nowcasting/forecasting mesoscale eddy activity on a regional basis in the Pacific. It was concluded that a joint university/INO task team approach would be instituted for both the California Current region and the Kuroshio Current region in the Pacific; these task teams would be put together by Dale Haidvogel. Implicit to this task team concept, it was assumed that INO would take advantage of the SIO URI activities in the development of its own nowcasting/forecasting capability, particularly in the California Current region. Therefore, a mechanism has now become available for the expertise and software developed by the SIO URI to be transferred to the operational navy community.

In the past two months, Robert Haney of the Navy Postgraduate School, has accepted an invitation to visit SIO this winter for the purpose of developing a capability for the assimilation of GEOSAT ERM altimetric sea level data into his multi-layered primitive equation model. Presently, assimilation studies conducted by the SIO URI have been restricted to the use of quasi-geostrophic models; so, this represents an opportunity to develop expertise and software that will be useful to the work of G. Vallis and A. Pares-Sierra, who are jointly developing a P.E. model of the California Current.

#### 4.0 Teaching of an SIO Navy Student

Ensign John M. Di Mento, a 1987 graduate of the Naval Academy at Annapolis, has been assigned to conduct post-graduate studies at SIO for a period of two years. John has decided to work with C.-K. Tai, Steve Pazan, and Warren B. White on the comparison of GEOSAT altimetric sea level data in the California Current with *in situ* observations consisting of available hydrographic and XBT data collected concurrently with the altimetric data. This study will be conducted for the first 18 months of the GEOSAT ERM; John will analyze both the altimetric data and the *in situ* observations collected at the Joint Environmental Data Analysis (JEDA) Center operated by Steve Pazan. The scientific results of intercomparisons of *in situ* and remotely-sensed data will constitute John's master's thesis.

## REFERENCES

- Bates, J., W. White, C.-K. Tai, and W.R. Holland, 1989. Realistic wind-driven quasi-geostrophic numerical simulation of the California Current (I): The non-eddy resolving model, (in progress).
- White, W.B., C.-K. Tai, and W.R. Holland, 1988. Continuous assimilation of simulated GEOSAT altimetric sea level into an eddy resolving numerical ocean model (Part I): Sea level differences. *J. Geophys. Res.* (in review).
- White, W.B., C.-K. Tai, and W.R. Holland, 1989. Continuous assimilation of simulated GEOSAT altimetric sea level into an eddy resolving numerical ocean model. (Part II): Referenced sea level differences. *J. Geophys. Res.*, (in review).
- White, W.B. and C.-K. Tai, (1988). Time and space scales of mesoscale eddy activity in the California Current region from the GEOSAT exact repeat mission. *J. Phys. Oceanogr.*, (in review).
- White, W.B., C.-K. Tai, and W.R. Holland, 1989. Continuous assimilation of GEOSAT altimetric sea level into a wind-driven non-eddy resolving numerical model of the California Current, (in progress).

# Modelling Activities

G.K. Vallis

W. Holland (NCAR)

A. Pares (pgr)

This is a summary of some of the modelling achievements under the URI program at Scripps. Some of the work described here was previously reported in the executive summary, prepared for the ONR site visit of June 1988.

Research may conveniently be divided into two categories: development and use of quasi-geostrophic models of the California Current system, and the development of a layered primitive equation model.

## *Quasi-geostrophic modelling*

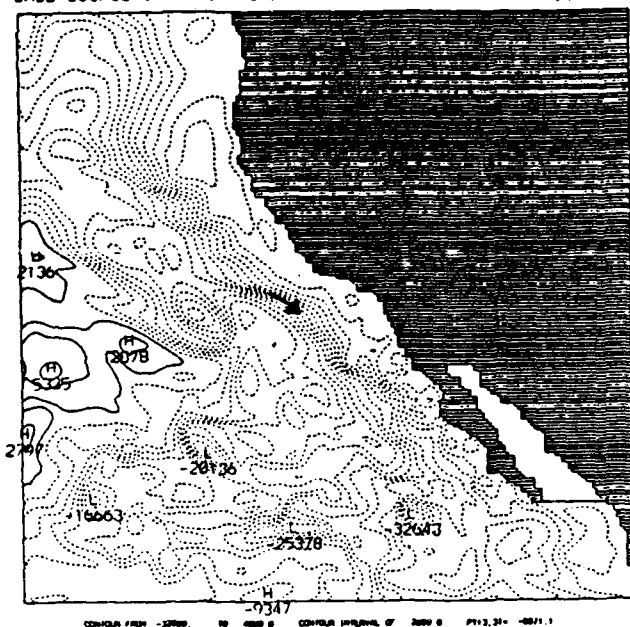
Development of a high resolution model of the California Current has largely been completed. The model has a resolution of  $1/6^\circ$  by eight vertical layers (although this may be altered at will). The geometry is realistic. The bathymetry is realistic, in so far as this may be achieved in a quasi-geostrophic model. The model is nested within a non-eddy resolving model of the North Pacific. A variety of experiments have been performed with it, principally to understand the influence of wind forcing and the boundary conditions. All experiments have used FNOC wind fields. In particular we have run experiments with daily wind, monthly averaged (seasonal) winds and with constant winds.

Fig. 1a shows a typical instantaneous upper-layer velocity field produced by the model. A clear 'California Current' is to be seen. Fig 1b shows the streamfunction field in model level 4, at about 700m deep. A strong northwards flowing California undercurrent is to be seen. This is one of the most notable, and least understood, observed features of the California Current system. It is present in the model even when the forcing is just constant, predominantly southward, winds. With the topography removed the countercurrent dies. This is a clear indication that eddy-topographic interactions are responsible for producing the northward undercurrent. Figs. 1c and 1d shows the eddy field - qualitatively very similar in scale to the eddy field seen from geosat. Note also the westward propagation of the eddies, another feature of the observations. These preliminary analyses show strong evidence that the model is reproducing the gross dynamics of the system. Energetic analyses and further diagnostics are underway. However, it is clear that the model already simulates some of the main features of the California Current. It is also clear that rather high resolution, both vertically and horizontally, is needed to resolve the eddies, which are an essential feature of the system. A grid of mesh size 20km is barely sufficient. We have begun a series of diagnostic tests and comparisons with available observational data to verify the model.



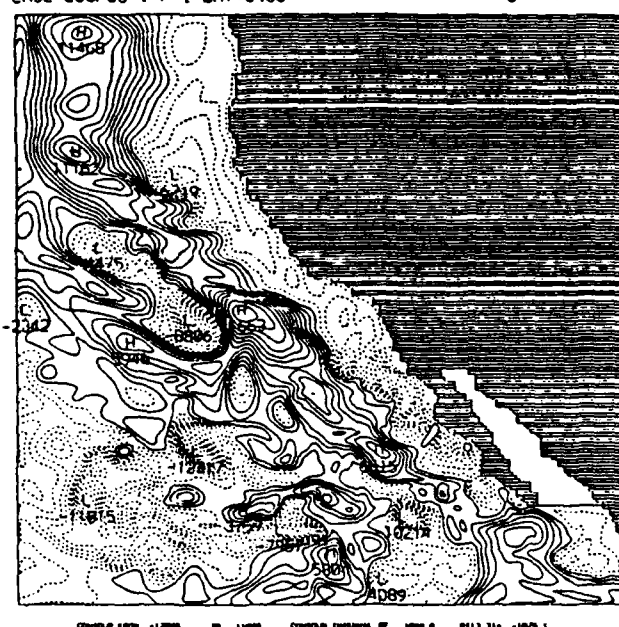
CASE C0UFC5-1 S-1 DAY=6400

A



CASE C0UFC5-1 P-1 DAY=6400

C



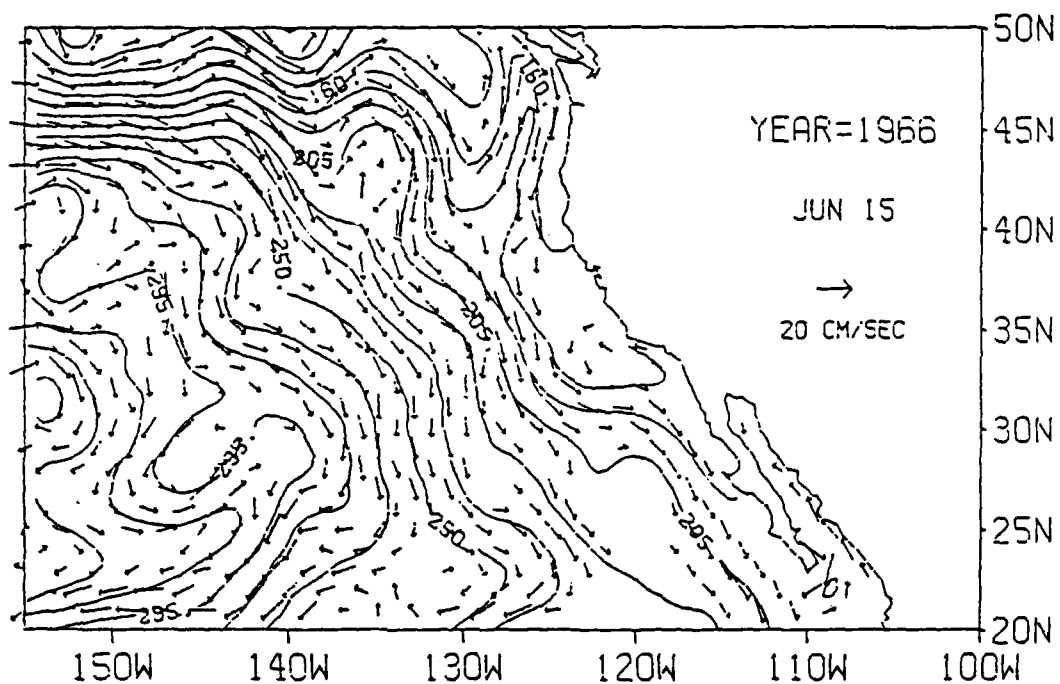


Fig. 2: Upper layer thickness (contours) and velocity (arrows). Typical output from the wind forced model. Arrows represent currents scaled according to the key in the figure. Contours are in meters. Contour interval is 15m. Currents slower than 1 cm/s are not plotted. Note area of ULT less than the initial 200m along the coast and in the northern region.

## SIO URI PROGRESS REPORT (SEPTEMBER, 1988)

Warren B. White and Chang-Kou Tai

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In the past two months, Drs. Harley Hurburt and Donn Blake from NORDA, have expressed a desire to coordinate their modeling activities in the eastern mid-latitude North Pacific (i.e., including the California Current region), with the activities presently ongoing in the SIO URI. They are expressly interested in collaborating both on the development and implementation of model/data

assimilation techniques, and on model verification. They plan to visit SIO in October to discuss the implementation of this collaboration. C.-K. Tai and Warren B. White see this collaboration as an important contribution by NORDA to the objectives of the SIO URI. Moreover, it is an opportunity for the orderly transfer of software technology from SIO to the Navy operational community. To facilitate this, it may be necessary for one or more of the NORDA personnel to conduct an extended visit at SIO during the later half of the URI, strengthening the collaboration between SIO and the operational Navy community. An additional possibility is that SIO operate the California Current eddy resolving model in a near-real time (i.e., nowcast/forecast) mode for both Navy and its own civilian use, following a precedent established with the SIO Remote Sensing Facility.

In the past two months, Dr. Warren White also attended a summer colloquium conducted under the auspices of the Institute of Naval Oceanography (INO), chaired by Dr. Christopher Mooers. At these meetings (held at Otter Creek during July 27-29, 1988), the task team approach taken by the SIO URI was promoted as a paradigm for developing a capability of nowcasting/forecasting mesoscale eddy activity on a regional basis in the Pacific. It was concluded that a joint university/INO task team approach would be instituted for both the California Current region and the Kuroshio Current region in the Pacific; these task teams would be put together by Dale Haidvogel. Implicit to this task team concept, it was assumed that INO would take advantage of the SIO URI activities in the development of its own nowcasting/forecasting capability, particularly in the California Current region. Therefore, a mechanism has now become available for the expertise and software developed by the SIO URI to be transferred to the operational navy community.

In the past two months, Robert Haney of the Navy Postgraduate School, has accepted an invitation to visit SIO this winter for the purpose of developing a capability for the assimilation of GEOSAT ERM altimetric sea level data into his multi-layered primitive equation model. Presently, assimilation studies conducted by the SIO URI have been restricted to the use of quasi-geostrophic models; so, this represents an opportunity to develop expertise and software that will be useful to the work of G. Vallis and A. Pares-Sierra, who are jointly developing a P.E. model of the California Current.

#### 4.0 Teaching of an SIO Navy Student

Ensign John M. Di Mento, a 1987 graduate of the Naval Academy at Annapolis, has been assigned to conduct post-graduate studies at SIO for a period of two years. John has decided to work with C.-K. Tai, Steve Pazan, and Warren B. White on the comparison of GEOSAT altimetric sea level data in the California Current with *in situ* observations consisting of available hydrographic and XBT data collected concurrently with the altimetric data. This study will be conducted for the first 18 months of the GEOSAT ERM; John will analyze both the altimetric data and the *in situ* observations collected at the Joint Environmental Data Analysis (JEDA) Center operated by Steve Pazan. The scientific results of intercomparisons of *in situ* and remotely-sensed data will constitute John's master's thesis.

## REFERENCES

- Bates, J., W. White, C.-K. Tai, and W.R. Holland, 1989. Realistic wind-driven quasi-geostrophic numerical simulation of the California Current (I): The non-eddy resolving model, (in progress).
- White, W.B., C.-K. Tai, and W.R. Holland, 1988. Continuous assimilation of simulated GEOSAT altimetric sea level into an eddy resolving numerical ocean model (Part I): Sea level differences. *J. Geophys. Res.* (in review).
- White, W.B., C.-K. Tai, and W.R. Holland, 1989. Continuous assimilation of simulated GEOSAT altimetric sea level into an eddy resolving numerical ocean model. (Part II): Referenced sea level differences. *J. Geophys. Res.*, (in review).
- White, W.B. and C.-K. Tai, (1988). Time and space scales of mesoscale eddy activity in the California Current region from the GEOSAT exact repeat mission. *J. Phys. Oceanogr.*, (in review).
- White, W.B., C.-K. Tai, and W.R. Holland, 1989. Continuous assimilation of GEOSAT altimetric sea level into a wind-driven non-eddy resolving numerical model of the California Current, (in progress).

9/2/88

RESIDUAL BALANCE SHEET  
URI NOOO14-86K-0752

P.I.-WHITE  
582476-25912  
BUDGET # 3857

	BALANCE AS OF AUG31,1988	PROJECTED EXPENSES	PROJECTED BALANCE SEPT30,1988
SALARIES & BENEFITS	(\$ 773)	\$0	(\$ 773)
SUPPLIES & EXPENSES	\$2,018	\$3,000	(\$ 982)
EQUIPMENT	\$178	\$0	\$178
TRAVEL	\$1,331	\$0	\$1,331
ADJ FOR OH	\$289	\$0	\$289
DIRECT TOTAL	\$3,043	\$3,000	\$43
OVERHEAD-45%	\$1,369	\$1,350	\$19
BUDGET TOTAL	\$4,412	\$4,350	\$62

PREPARED BY:  
JOAN DURKIN